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Hour-by-hour physical activity patterns of adults aged 45–65 years: a cross-sectional study

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ABSTRACT

Background Limited information exists on hour-by-hour physical activity (PA) patterns among adults aged 45–65 years. Therefore, this study aimed to distinguish typical hour-by-hour PA patterns, and examined which individuals typically adopt certain PA patterns.

Methods Accelerometers measured light and moderate-vigorous PA. GIS-data provided proportions of land use within an 800 and 1600 m buffer around participant's homes. Latent class analyses were performed to distinguish PA patterns and groups of individuals with similar PA patterns.

Results Four PA patterns were identified: a morning light PA pattern, a mid-day moderate-vigorous PA pattern, an overall inactive pattern and an overall active pattern. Groups of individuals with similar PA patterns differed in ethnicity, dog ownership, and the proportion of roads, sports terrain, larger green and blue space within their residential areas.

Conclusions Four typical hour-by-hour PA patterns, and three groups of individuals with similar patterns were distinguished. It is this combination that can substantially contribute to the development of more tailored policies and interventions. PA patterns were only to a limited extent associated with personal and residential characteristics, suggesting that other factors such as work time regimes, family life and leisure may also have considerable impact on the distribution of PA throughout the day.

Keywords environment, physical activity, public health

Introduction

Globally, 31.1% of adults does not comply with recommendations for physical activity (PA).[1] This suggests that it may be difficult to integrate sufficient PA in one's daily life. Although moderate-vigorous PA (MVPA) has been known for its positive health effects,[2] recently, researchers have emphasized the importance of light-intensity PA (LPA) for health as well,[2] and LPA is often easier to integrate in daily life. Various studies found that adults spend indeed more time in daily LPA than in daily MVPA.[3,4]

Apart from the amount of LPA and/or MVPA per day or per week, it is relevant to investigate how PA is distributed in time. For instance, interrupted sedentary behavior is less harmful to health than prolonged sedentary behavior.[5] Also, investigating patterns of adults' PA behaviors throughout the day may give insight into critical time-windows to intervene in.[6] Especially time constraints may restrict adults to integrate PA in their daily lives,[7] and insight in their hour-by-hour PA patterns and their socio-demographic and residential environmental characteristics may contribute to understanding why their PA levels are low. Moreover, integrating PA in daily life may be more difficult for specific subpopulations (e.g. adults with (full-time) employment),[7] and information on their hour-by-hour PA patterns may provide insight in whether time periods that may be used for PA (e.g. employed adults who

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participate in sports or PA during the evenings or on weekend days) are actually used.

Only a few studies investigated how adults' PA behavior was structured throughout a week,[8–11] or throughout the day.[11–18] Most of these studies compared PA levels between specific a priori determined subpopulations, e.g. women workers versus women at home,[16] patients versus healthy adults,[14] normal weight versus overweight and obese adults,[13] least, medium and most active adults,[15] and adults residing in neighborhoods with different levels of neighborhood walkability.[12] Due to this focus on specific subpopulations, little is known about the hour-by-hour distribution of light PA and moderate-to-vigorous PA of a more general adult population, and the variation in such distributions. Cerin *et al.*[11] provided data on MVPA minutes throughout the day and assessed whether associations between these MVPA levels and environmental characteristics differed throughout the day and between weekend and weekdays. However, evidence on what different types of daily LPA and MVPA patterns are typically adopted by different subpopulations, is scarce.

Of particular interest are adults aged 45–65 years, the so called 'sandwich generation', who face the challenge of combining work responsibilities with the care for both their children and their aging parents.[19] This impacts their daily activities, including time left for PA. Determining what PA patterns exist, and how these are related to socio-demographic factors (e.g. sex, ethnicity and employment) is important to tailor PA interventions. Besides, environmental opportunities for PA may also play a role in hour-by-hour PA patterns.[6,12] For example, adults living in neighborhoods with many sports facilities may have higher (MV)PA levels in the evening and on weekend days. Hence, both socio-demographic and residential environmental characteristics may affect how individuals' PA levels are distributed through time.

Therefore, this study aims (i) to investigate which typical daily hour-by-hour PA patterns (i.e. indicated by levels of LPA and MVPA) exist in an adult population aged 45–65 years and (ii) to identify individuals (based on socio-demographic factors and land use characteristics of residential areas) that typically adopt certain PA patterns.

Methods

Study sample

This cross-sectional study is part of the PHASE (Physical Activity in public Space Environments) project, which aimed to investigate PA behavior of adults aged 45–65 years.[20] Participants were randomly recruited among residents aged 45–65 years, living in Rotterdam and Maastricht, the Netherlands. After sending an invitation letter to a sample of 14 889 adults, $N = 516$ registered for the study, and $N = 406$ wore an accelerometer and GPS-device for 7 days from April to December 2014. All participants signed informed consent. This study was approved by the review board of the Social and Behavioural Sciences faculty of Utrecht University.

Measures

Actigraph GT3X+ accelerometers (Actigraph, Pensacola, FL) measured PA, and data were downloaded using Actilife v6.11.2. Vector magnitude cut-points for triaxial accelerometer counts were used to define light PA (150–3208 cpm), moderate PA (3208–8564 cpm) and vigorous PA (≥ 8565 cpm).[21,22] MVPA was the sum of moderate and vigorous PA. The 70/80 rule was used to define a valid day.[23] For the analyses, only days that had sufficient data for the hours between 9 AM and 9 PM (i.e. at least 360 epochs per hour) were included. Including hours before 9 AM and/or after 9 PM led to considerable data loss as the amount of days that had sufficient data for each of those hours substantially reduced. After applying these criteria for valid data, 562 days of 222 participants (141 Maastricht, 81 Rotterdam) were included.

The coordinates of participants' home addresses were mapped in ArcMap 10.2.2 (Esri, Redlands, CA), around which buffers of 800 and 1600 m were drawn. For each buffer the proportions of nine different land uses (Statistics Netherlands, 2012) were calculated: residences, roads, shopping facilities and hospitality industry (e.g. supermarkets, hotels), public social–cultural facilities (i.e. educational institutes, hospitals), sports terrain (e.g. football fields, swimming pool), recreational area (e.g. picnic places, zoos), city green (e.g. city parks, allotments), larger green (e.g. forests, moorlands) and blue space (e.g. rivers, lakes).

A questionnaire was used to obtain information on home address, age, sex, BMI, health status, ethnicity, education, employment, having children, having a dog and sports participation. Detailed descriptions on how ethnicity, education and employment were defined, were provided elsewhere.[20,24]

Statistical analyses

To distinguish typical hour-by-hour PA patterns, we evaluated respondents' daily LPA and MVPA patterns, defined by the percentages of LPA and MVPA in each hour. To assess whether there were similarities in the observed patterns, LatentGOLD 5.1 software (Statistical Innovations, Belmont) was used to fit a latent class regression (LCR) model which clusters the $N = 562$ days into a smaller number of latent classes which have similar daily patterns.[25] Second, LatentGOLD was used to assess

clusters of individuals that typically adopted certain PA patterns. Since we observed multiple days within most individuals, a multilevel extension was used to accommodate for correlations between observed PA patterns due to person-specific characteristics. The multilevel LCR model was used to classify each respondent according to the distribution of particular PA patterns within that person. For example, all respondents who had many active daily patterns and only few inactive daily patterns could be clustered into one class. Each individual was assigned to the class they most likely belonged to according to the posterior membership probabilities (i.e. modal assignment was used).

To find the best fitting model, we estimated models with different specifications regarding the number of classes for the daily patterns and the respondents. To model the class-specific patterns, we used regression splines which are more flexible than traditional polynomials. We estimated models with 1–9 latent classes for the daily PA patterns and 1–7 classes for the clusters of individuals. Three criteria were used to select the best fitting models, and hence the final number of classes.[26] The first criterion was the BIC, which indicates the trade-off between model-fit and model-complexity, with lower values meaning a better trade-off.[27] However, in LCR models, the BIC is known to select a very large number of classes, because the complexity of the model increases little when adding an extra class. To limit the chances of over fitting (i.e. selecting more classes than necessary), the second criterion was to require each class to comprise at least 15% of all observations. The third criterion included a visual inspection to retain interpretability of what each class represented. SPSS was used for descriptive statistics, ANOVA, chi-square and Kruskall–Wallis analyses.

Results

Participants

Participants had an average age of 56.8 years (SD 6.1), and 52.7% were females (Table 1). Almost half of participants were overweight or obese, and more than 80% reported a good or very good health status. The majority was native Dutch, and had a middle or higher education. Over half of the participants was employed. One-third had at least one child aged <18 years living at home, and 18.5% had a dog. Land use within both buffers mainly consisted of residences.

Hour-by-hour PA behavior

Four different types of daily hour-by-hour PA patterns were distinguished (i.e. days with similar patterns, further referred

Table 1 Study sample ($N = 222$)

Socio-demographic factors	
Age in years, mean (± SD)	56.8 (±6.1)
Female (%)	52.7
BMI (%)	
Healthy weight	56.3
Overweight	34.7
Obesity	9.0
Health status (%)	
Very good	20.7
Good	60.4
Fair	14.0
Poor	4.5
Very poor	0.5
Ethnicity (%)	
Autochthonous	85.1
Western immigrants	5.9
Non-western immigrants	7.7
Missing	1.3
Education (%)	
Low	4.1
Middle	53.2
High	42.3
Missing	0.4
Employed (%)	57.7
Having children (living at home) (%)	33.3
Having a dog (%)	18.5

GIS-based land-use characteristics	*Median %*	*Interquartile range*
Residences		
800 m	54.24	(44.46; 62.21)
1600 m	37.03	(30.24; 45.40)
Roads		
800 m	5.51	(3.78; 7.13)
1600 m	5.56	(4.67; 6.32)
Shopping facilities and hospitality industry		
800 m	2.01	(1.55; 3.78)
1600 m	1.89	(1.27; 4.49)
Public social cultural facilities		
800 m	2.61	(1.16; 6.05)
1600 m	4.07	(2.27; 6.90)
Sports terrain		
800 m	2.33	(1.08; 3.48)
1600 m	3.07	(2.20; 5.75)
Recreational area		
800 m	0.00	(0.00; 1.04)
1600 m	0.44	(0.11; 1.87)

Continued

Table 1 Continued

GIS-based land-use characteristics	*Median %*	*Interquartile range*
City green		
800 m	6.12	(3.79; 8.35)
1600 m	5.49	(3.82; 8.53)
Larger green		
800 m	3.08	(0.00; 10.98)
1600 m	8.54	(1.52; 26.46)
Blue space		
800 m	0.00	(0.00; 8.94)
1600 m	2.83	(0.00; 16.05)

SD = standard deviation; BMI = body mass index; GIS = geographical information system.

to as 'day types') (Fig. 1). Day type 1 describes a pattern of medium-high LPA percentages, with a peak between 10 and 12 AM, and a steep decline of LPA after 6 PM. The MVPA percentages of day type 1 are continuously very low throughout the day. Hence, day type 1 is referred to as a morning LPA pattern, which occurred relatively more often on Saturdays (Table 2). Day type 2 describes a pattern of medium-low LPA levels, with a steep decline after 6 PM. Day type 2 has the highest MVPA percentages. This pattern starts with an increase of MVPA till the highest level is reached between 11 AM and 1 PM. Then, MVPA continuously declines until it stabilizes from 7 to 9 PM. Day type 2 is referred to as a mid-day MVPA pattern, which occurred relatively more often on a Saturday (Table 2). Day type 3 has the lowest LPA percentages. The highest LPA percentage is reached between 6 and 7 PM, and a steep decline after 7 PM. MVPA percentages of day type 3 are second lowest. Day type 3 is referred to as an overall inactive pattern, which occurred relatively more often on a Friday (Table 2). Day type 4 has the highest LPA percentages and the second highest MVPA percentages. LPA and MVPA increase in the morning, with the highest levels between 11 and 12 AM. Day type 4 is referred to as an active pattern, which occurred relatively more often on Mondays and Thursdays.

Hour-by-hour LPA and MVPA patterns in different groups of individuals

Three different groups of individuals were distinguished that typically adopted certain PA patterns (Table 3). These groups differed significantly with respect to their ethnicity, whether or not they had a dog, and some characteristics of their residential areas, i.e. proportions of larger green space within an 800 m buffer, proportions of roads and sports terrain within a 1600 m buffer, and proportions of blue space within both an 800 and 1600 m buffer.

None of the three groups had day type 3 as the predominant pattern. Individuals in group one were most likely to have hour-by-hour PA patterns of day type 2. This group had a significantly higher percentage of native Dutch adults than the other groups. The group had the lowest proportion of larger green within an 800 m buffer, and the highest proportions of blue space in both buffers. Individuals in group 2 were most likely to have hour-by-hour PA patterns of day type 1. This group had a significantly lower percentage of dog owners than the other groups. The group had the lowest proportion of roads, and the highest proportion of sports terrain, within a 1600 m buffer. It also had the highest proportion of larger green within an 800 m buffer. Individuals in group three were most likely to have hour-by-hour PA patterns of day type 4. The percentage of non-western immigrants in this group was significantly higher than in the other groups. This group had significantly less sports terrain within a 1600 m buffer.

Discussion

Main findings of this study

This study enhances the field of PA research by using multilevel latent growth models to distinguish hour-by-hour PA patterns in objectively collected LPA and MVPA data, and by classifying individuals based on their PA patterns without making a priori assumptions on group composition. Four typical hour-by-hour PA patterns were distinguished: (i) a morning LPA pattern, (ii) a mid-day MVPA pattern, (iii) an overall inactive pattern and (iv) an overall active pattern. Individuals with similar combinations of these patterns over the course of several days also appeared to be similar regarding some individual characteristics (i.e. ethnicity and having a dog) and residential area characteristics (i.e. proportion of roads, sports terrain, larger green space and blue space).

What is already known on this topic, and what this study adds

Whereas most previous studies reported total daily PA levels, the time-specific data of the current study draws attention to periods of the day when adults are less active which could be targeted for intervention. The hour-by-hour analyses indicated that evenings may be an important intervention opportunity as for this time period the lowest levels of both LPA and MVPA were observed in all four daily PA patterns. There may be different explanations for these low evening PA levels. Adults—in particular older adults—may

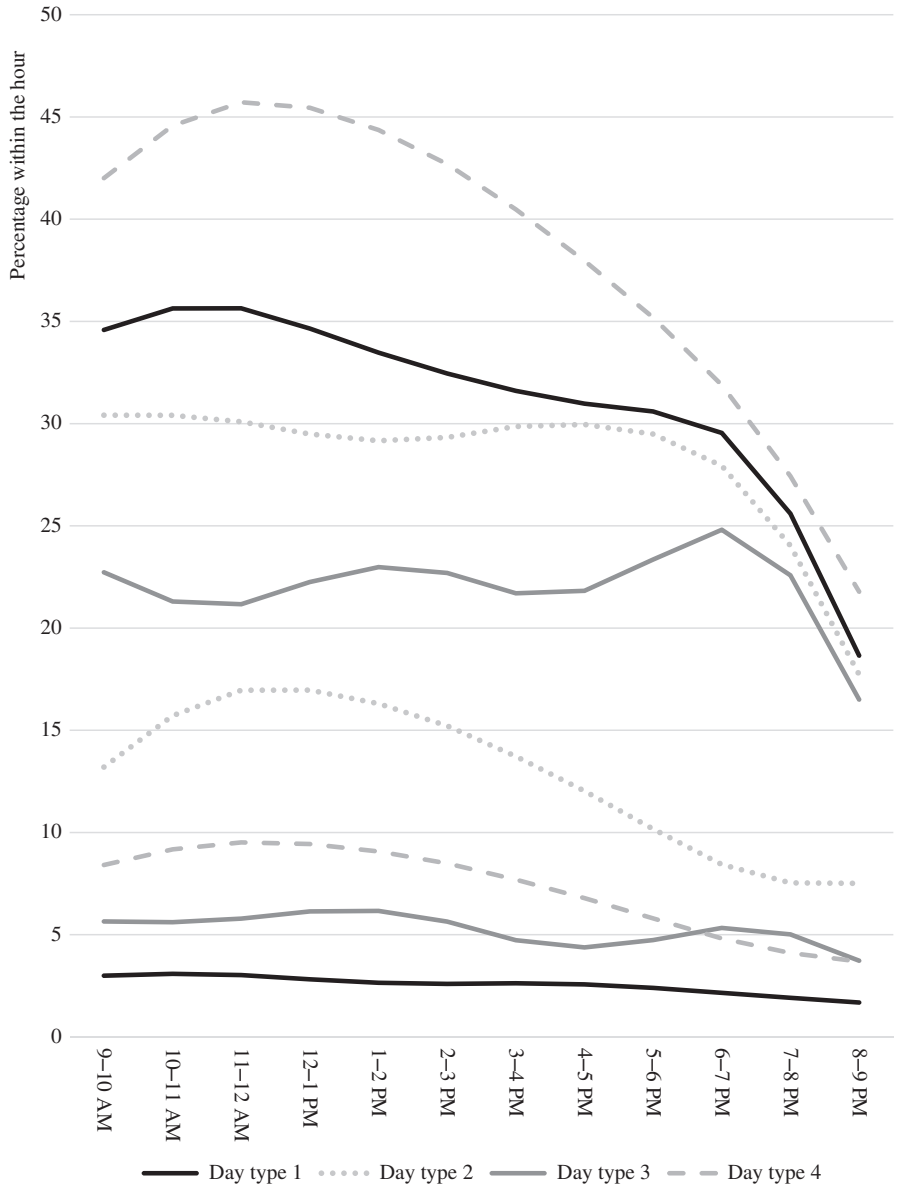

Fig. 1 Four different day types of hour-by-hour LPA (top) and MVPA (bottom).

experience constraints to go out in the evening[28] due to, e.g. feelings of unsafety (e.g. related to absence of street lighting, or presence of crime).[29,30] Another explanation may be that adults who engage in PA throughout the day, e.g. when they have a job that requires them to be physically active, may be too tired to engage in PA in the evenings.

Furthermore, the overall inactive PA pattern is of concern for adverse health outcomes, and more than 15% of the observed days in our sample were of the inactive type. Although none of the three groups of individuals with distinctive combinations of certain day types had the inactive PA patterns as their predominant pattern, group 1 still has a considerable chance of having an inactive day pattern. As high PA levels can attenuate the adverse health effects of prolonged sitting time,[31] it is important that inactive days are compensated by more active days (i.e. day type 4), or by day types that have higher PA levels in specific time windows (e.g. day type 1 or 2). Well-targeted interventions may replace inactive days by, e.g. morning LPA patterns or mid-day MVPA patterns (e.g. by integrating more PA at work and more active transport to work).

Higher PA levels were observed in the other three patterns. Although the morning LPA pattern had the lowest MVPA levels throughout the day, it had the second highest LPA levels with a peak in the morning. As this pattern was mostly observed on Saturdays, perhaps these higher LPA levels in the morning may reflect active travel to the grocery store or

Table 2 Description of the four day types according to prevalence (i.e. share of total observed days), levels of LPA and MVPA, and occurrence by day of the week

	Prevalence of day type[a]	*Levels of LPA and MVPA*			*Days of the week (%)*[b]							*Pattern description*
		Lowest	*Medium*	*Highest*	*Mo*	*Tu*	*We*	*Th*	*Fr*	*Sa*	*Su*	
Day type 1	25.4%				14.9	10.1	8.3	16.7	11.3	20.2	18.5	Morning LPA pattern
LPA			X									Highest in the morning
MVPA		X										Constant, lowest levels
Day type 2	30.2%				13.9	10.3	11.5	17.0	17.6	20.6	9.1	Mid-day MVPA pattern
LPA			X									Rather constant, but with a steep decline in the evening
MVPA				X								Increase in the morning, peak between 11 AM and 1 PM
Day type 3	15.2%				16.8	15.4	9.1	16.8	18.2	14.0	9.8	An overall inactive day pattern
LPA		X										Low, irregular undulating, peak between 6 and 7 PM
MVPA			X									Overall medium-low
Day type 4	29.2%				20.9	7.0	7.0	20.9	18.6	9.3	16.3	An overall active day pattern
LPA				X								Overall highest, increase in the morning
MVPA			X									Medium-high levels, increase in the morning

[a]The percentages reflect the share of the total observed days for each day type. For example, 25.4% of all observed days within the sample had a day type 1 pattern. [b]The percentages reflect the share of all observed days of a specific day type that occurred on each day of the week. For example, 14.9% of all days that were assigned to day type 1 occurred on a Monday.

sports clubs of their children. The mid-day MVPA pattern showed second lowest LPA levels, and highest MVPA levels —with a peak around mid-day. This pattern was also mostly observed on Saturdays and may therefore perhaps reflect adults' sports activities. Finally, the overall active pattern had both high LPA and MVPA levels. As this pattern mostly occurred on weekdays, it may reflect PA during work.

Adults of group 2, who were most likely to have a morning LPA pattern (i.e. day type 1), less often owned a dog compared to the other groups. As dog ownership is known to positively relate to (MV)PA,[20,32] this may partly explain their lower PA levels compared to other adults. Moreover, although not significantly different from the other groups, group 2 had the highest prevalence of having at least one child living at home. Their low levels of MVPA are in line with evidence showing a negative association between MVPA and having children.[20] Perhaps these adults' MVPA levels can be increased by interventions that aim to stimulate MVPA during the evenings and weekend days. Besides, group 2 had the highest proportions of sports terrain within a 1600 m buffer and larger green spaces within an 800 m buffer. This may explain why the morning LPA pattern mostly occurred on Saturdays, as sports and visits to, e.g. forests often take place during the weekends.

The mid-day MVPA pattern (i.e. day type 2) was most common among native Dutch adults (group 1). This is consistent with previous studies showing lower levels of PA for ethnic minority groups.[33] Day type 2 mostly occurred on Saturdays, which may be because of higher levels of sports participation on Saturdays compared to other days of the week. Additionally, the results showed that group 1 (i.e. which had most chance of this day type 2) had the highest proportions of blue space in their residential environments. Although current literature shows that blue space can be seen as activity-promoting, it is often associated with low-intensity activities (e.g. walking).[34] Perhaps in the Netherlands blue space also elicits high-intensity activities such as jogging. However, the design of the current study does not allow for causal inferences to be drawn between environmental characteristics and PA. Future research may examine whether the presence of blue space in residential environments contributes to more active PA patterns, or that adults who prefer an active lifestyle choose to reside in a neighborhood with blue spaces.

Furthermore, day type 4, consisting of both high LPA and MVPA levels, was most likely among the group with a significantly higher prevalence of non-western immigrants (i.e. group 3). Although this may seem unexpected, as being of ethnic origin has been related to lower levels of PA,[33] it

Table 3 Descriptive statistics of the different groups of adults (based on their PA patterns)

	Group 1 (N = 114)	*Group 2 (N = 63)*	*Group 3 (N = 45)*
PA behavior			
Hour-by-hour PA			
Day type 1—morning LPA pattern	0.10	0.63	0.01
Day type 2—mid-day MVPA pattern	0.49	0.11	0.15
Day type 3—overall inactive pattern	0.24	0.09	0.04
Day type 4—overall active pattern	0.17	0.17	0.80
Socio-demographic characteristics			
Age in years, mean (± SD)	57.4 (± 6.0)	56.1 (± 6.6)	56.2 (± 5.6)
Female (%)	48.2	54.0	62.2
BMI (%)			
Healthy weight	60.5	49.2	55.6
Overweight	32.5	41.3	31.1
Obesity	7.0	9.5	13.3
Health status (%)			
(Very) Good	81.6	82.5	77.7
Fair	14.9	11.1	15.6
(Very) Poor	3.5	6.4	6.7
Ethnicity (%)			
Autochthonous*	93.0	82.5	68.9
Western immigrant	4.4	9.5	4.4
Non-western immigrant*	2.6	6.3	22.2
Missing	0.0	1.6	4.4
Education (%)			
Low	3.5	3.2	6.7
Middle	46.5	57.1	64.4
High	49.1	39.7	28.9
Missing	0.9	0.0	0.0
Employed (%)	57.0	55.6	62.2
Missing	1.8	1.6	0.0
Having children (%)	28.1	44.4	31.1
Having a dog* (%)	24.6	4.8	23.3
Participates in sports (%)	71.9	57.1	60.0
Environmental characteristics, median % (IQR)[a]			
Residences			
800 m	58.87 (44.46; 62.76)	52.18 (44.83; 61.18)	56.09 (37.86; 64.29)
1600 m	37.82 (32.26; 46.46)	35.84 (30.10; 41.21)	38.11 (29.01; 48.83)
Roads			
800 m	5.48 (4.46; 7.35)	5.00 (3.24; 6.65)	5.79 (3.56; 7.22)
1600 m*	5.71 (4.83; 5.71)	5.24 (3.18; 5.85)	5.67 (4.91; 6.35)
Shopping facilities and hospitality industry			
800 m	2.24 (1.55; 4.46)	1.98 (1.09; 2.89)	1.77 (1.45; 4.73)
1600 m	2.07 (1.34; 4.51)	1.76 (1.04; 2.91)	1.88 (0.91; 4.79)
Public social cultural facilities			
800 m	2.74 (1.21; 6.73)	1.64 (0.88; 3.75)	3.24 (0.89; 6.39)
1600 m	4.13 (2.27; 6.85)	3.43 (1.66; 6.92)	4.48 (2.52; 6.94)
Sports terrain			
800 m	2.14 (1.01; 3.19)	2.77 (1.36; 4.84)	2.63 (1.21; 3.21)
1600 m*	3.00 (2.18; 4.42)	3.56 (2.63; 8.08)	2.74 (1.93; 5.84)

Continued

Table 3 Continued

	Group 1 (N = 114)	*Group 2 (N = 63)*	*Group 3 (N = 45)*
Recreational area			
800 m	0.0 (0.0; 1.67)	0.0 (0.0; 1.04)	0.0 (0.0; 0.73)
1600 m	0.44 (0.04; 1.36)	0.44 (0.18; 1.36)	0.85 (0.22; 2.42)
City green			
800 m	5.98 (2.43; 8.76)	5.74 (3.01; 8.56)	6.78 (5.11; 7.82)
1600 m	6.07 (3.83; 10.83)	5.42 (3.82; 7.74)	4.83 (3.52; 7.60)
Larger green			
800 m*	1.23 (0.0; 8.12)	4.19 (0.0; 21.92)	3.90 (0.0; 15.77)
1600 m	5.20 (1.13; 21.77)	12.38 (2.20; 32.59)	9.70 (2.46; 30.20)
Blue space			
800 m*	1.40 (0.0; 12.53)	0.0 (0.0; 6.39)	0.0 (0.0; 3.78)
1600 m*	3.86 (0.15; 20.87)	0.14 (0.0; 12.37)	2.79 (0.0; 7.63)

SD = Standard deviation; IQR = interquartile range. [a]Medians are presented as these variables were not normally distributed. *Significant differences were found between groups.

may be (partly) explained by the prevalences of employed and lower educated adults within this group. Previous studies have shown that education was inversely associated with (occupational) PA.[20,35] That is, lower educated adults might more often have jobs that require PA. This thought is supported by the high prevalence of lower educated, employed adults in this group, and by the finding that this pattern mostly occurred on weekdays. Another somewhat unexpected finding is that this group had the lowest levels of sports terrain within a 1600 m buffer. Although one may expect that the presence of sports facilities contributes to an increase in PA (intensity), these findings suggest that other public, or work spaces may be of equal or even more importance. This is in line with previous findings which showed that a variety of locations are used for (MV)PA.[20]

Where previous studies found associations between various socio-demographic and environmental factors and PA, this study found that typical PA patterns were only to a limited extent associated with personal (i.e. ethnicity and having a dog) and residential characteristics (i.e. roads, sports terrain, larger green space and blue space). This suggests that when it comes to hour-by-hour PA patterns, other factors such as time regimes of work, family life and leisure may have a considerable impact on the distribution of PA throughout the day. Hence, time-interval specific interventions cannot just be applied to 'traditional' target groups such as lower educated or non-native adults, but should consider evidence on daily PA patterning.

By using a data-driven approach to distinguish different types of hour-by-hour PA patterns that were typically adopted by subpopulations, this study showed that individual and environmental characteristics are associated to the manner in which LPA and MVPA are distributed through time. In addition, it showed that both the amount of LPA and MVPA and their distribution across time of day were associated with day of the week. By showing that adults are likely to have different daily PA patterns due to varying constraints and opportunities related to individual and environmental factors, it expands current literature that showed that different subpopulations have different total PA levels. However, as this study found only few associations, other factors such as work regime, family life, and leisure, that were not assessed, may affect PA patterns too.

Limitations of this study

It should be noted that, while clusters of PA patterns are identified, considerable variation exists within clusters. For example, one may find PA peaks during the evening for some adults, despite the average declining trend in PA during the evening. When such a pattern is not frequent enough among the study population, these peaks will not be reflected in the average hour-by-hour PA patterns of each cluster depicted in Fig. 1. A larger study sample may yield more diverse PA patterns that give rise to additional time specific interventions.

Although the response rate of this study (516 of the 14 889 invited adults registered for participation) was rather low, the final study sample was comparable to other studies in the PA field. In comparison to the average Dutch 45–65-year-old adult population, immigrants (both western and non-western) and low educated adults were

underrepresented in this study. Furthermore, it is likely that adults who registered to participate have an interest in active living, and hence their PA levels may be higher than the average 45–65-year-old adult population. Although the effect of this selection bias is unclear, it may be that PA levels were overestimated in this study.

This rich data provides many opportunities for further investigation, and future research may for example assess the association between individual characteristics of adults who had during the day at least 1 h of 100% LPA or MVPA, or distinguish the locations where peaks and troughs of LPA or MVPA take place.

In the current study we were interested in identifying distinct groups. Due to the nature of the used classification method (i.e. modal assignment based on posterior membership probabilities), classification errors may have been made. Though, most of the classifications in this study were very clear and the effect of the errors will be low.

Conclusions

This study applied a novel approach to explore adults' daily PA patterns. Where previous studies mostly aimed to compare PA patterns of a priori defined subpopulations, this study used detailed and objectively collected PA data as a starting point to examine what daily PA patterns could be distinguished, and additionally to assess what different groups of individuals could be distinguished, based on these patterns. This approach may offer new clues of how to define target groups for time-specific PA interventions, which take into account individuals' daily and weekly time regimes. The main conclusions that can be drawn based on the findings of the current study are that (i) different hour-by-hour PA patterns exist between adults with different socio-demographic and residential environmental characteristics, and (ii) PA peaks occur in different patterns in the morning or around mid-day, whereas in all patterns PA levels are low in the evening. These findings suggest that interventions that aim to increase PA levels should be very accurately tailored due to the variety in PA patterns between subpopulations. This may therefore lead to less generic interventions, possibly based on observations of current PA behavior of adults. However, more and in depth research is necessary to support and expand current findings to inform policy in more detail.

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Conflicts of interest

None declared.

References

1 Hallal PC, Andersen LB, Bull FC *et al.* Global physical activity levels: surveillance progress, pitfalls, and prospects. *Lancet* 2012;**380**:247–57.

2 Warburton DER, Bredin SSD. Reflections on physical activity and health: what should we recommend? *Can J Cardiol* 2016;**32**:495–504.

3 Healy GN, Wijndaele K, Dunstan DW *et al.* Objectively measured sedentary time, physical activity, and metabolic risk the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Diabetes Care* 2008; **31**:369–71.

4 Owen N, Bauman A, Brown W. Too much sitting: a novel and important predictor of chronic disease risk? *Br J Sports Med* 2009;**43**:81–3.

5 Healy GN, Matthews CE, Dunstan DW *et al.* Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 200306. *Eur Heart J* 2011;**32**:590–7.

6 Van Cauwenberghe E, Jones RA, Hinkley T *et al.* Patterns of physical activity and sedentary behaviour in preschool children. *Int J Behav Nutr Phys Act* 2012;**9**:138.

7 Deelen I, Ettema D, Dijst M. Too busy or too far away? The importance of subjective constraints and spatial factors for sports frequency. *Manga Sport Leis* 2016;**21**:239–64.

8 Metzger JS, Catellier DJ, Evenson KR *et al.* Patterns of objectively measured physical activity in the United States. *Med Sci Sports Exerc* 2008;**40**:630–8.

9 Evenson KR, Wen F, Metzger JS *et al.* Physical activity and sedentary behavior patterns using accelerometry from a national sample of United States adults. *Int J Behav Nutr Phys Act* 2015;**12**:20.

10 Jones SA, Wen F, Herring AH *et al.* Correlates of US adult physical activity and sedentary behavior patterns. *J Sci Med Sport* 2016;**19**:1020–27.

11 Cerin E, Mitáš J, Cain KL *et al.* Do associations between objectively-assessed physical activity and neighbourhood environment attributes vary by time of the day and day of the week? IPEN adult study. *Int J Behav Nutr Phys Act* 2017;**14**:34.

12 Arvidsson D, Eriksson U, Lönn SL *et al.* Neighborhood walkability, income, and hour-by-hour physical activity patterns. *Med Sci Sports Exerc* 2013;**45**:698–705.

13 Cooper AR, Page A, Fox KR *et al*. Physical activity patterns in normal, overweight and obese individuals using minute-by-minute accelerometry. *Eur J Clin Nutr* 2000;**54**:887–94.

14 Rietberg MB, Van Wegen EEH, Kollen BJ *et al*. Do patients with multiple sclerosis show different daily physical activity patterns from healthy individuals? *Neurorehabil Neural Repair* 2014;**28**:516–23.

15 Garriguet D, Colley RC. Daily patterns of physical activity among Canadians. *Health Rep* 2012;**23**:1–7.

16 Steeves JA, Murphy RA, Zipunnikov V *et al*. Women workers and women at home are equally inactive: NHANES 2003–2006. *Med Sci Sports Exerc* 2015;**47**:1635–42.

17 Steeves JA, Murphy RA, Crainiceanu CM *et al*. Daily patterns of physical activity by type 2 diabetes definition: comparing diabetes, prediabetes, and participants with normal glucose levels in NHANES 2003–2006. *Prev Med Rep* 2015;**2**:152–57.

18 Mai A, Bloch A, Klaaßen-Mielke R *et al*. Diurnal profiles of pedometer-determined physical activity in chronically ill and mobility-limited older adults: a cross-sectional study. *BMC Public Health* 2014;**14**:1268.

19 Riley LD, Bowen C. The sandwich generation: challenges and coping strategies of multigenerational families. *Fam J* 2005;**13**:52–8.

20 Jansen FM, Ettema DF, Pierik FH *et al*. Sports facilities, shopping centers or homes: what locations are important for adults' physical activity? A cross-sectional study. *Int J Environ Res Public Health* 2016;**13**:287.

21 Carr LJ, Mahar MT. Accuracy of intensity and inclinometer output of three activity monitors for identification of sedentary behavior and light-intensity activity. *J Obes* 2012;**2012**:1–9.

22 Santos-Lozano A, Santín-Medeiros F, Cardon G *et al*. Actigraph GT3X: validation and determination of physical activity intensity cut points. *Int J Sports Med* 2013;**34**:975–82.

23 Catellier DJ, Hannan PJ, Murray DM *et al*. Imputation of missing data when measuring physical activity by accelerometry. *Med Sci Sports Exerc* 2005;**37**:S555–62.

24 Jansen FM, Ettema DF, Kamphuis CBM *et al*. How do type and size of natural environments relate to physical activity behavior? *Health Place* 2017;**46**:73–81.

25 Muthén B. Latent variable analysis. In: Kaplan D (ed). *The Sage Handbook of Quantitative Methodology for the Social Sciences*. Thousand Oaks, CA: Sage Publications, 2004,345–68.

26 Evenson KR, Wen F, Hales D *et al*. National youth sedentary behavior and physical activity daily patterns using latent class analysis applied to accelerometry. *Int J Behav Nutr Phys Act* 2016:13:55.

27 Schwarz G. Estimating the dimension of a model. *Ann Stat* 1978;**6**: 461–64.

28 Crombie IK, Irvine L, Williams B *et al*. Why older people do not participate in leisure time physical activity: a survey of activity levels, beliefs and deterrents. *Age Ageing* 2004;**33**:287–92.

29 Moran M, Van Cauwenberg J, Hercky-Linnewiel R *et al*. Understanding the relationships between the physical environment and physical activity in older adults: a systematic review of qualitative studies. *Int J Behav Nutr Phys Act* 2014;**11**:79.

30 Calogiuri G, Chroni S. The impact of the natural environment on the promotion of active living: an integrative systematic review. *BMC Public Health* 2014;**14**:873.

31 Ekelund U, Steene-Johannessen J, Brown WJ *et al*. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonized meta-analysis of data from more than 1 million men and women. *Lancet* 2016;**388**: 1302–10.

32 Christian HE, Westgarth C, Bauman A *et al*. Dog ownership and physical activity: a review of the evidence. *J Phys Act Health* 2013;**10**: 750–59.

33 Trost SG, Owen N, Bauman AE *et al*. Correlates of adults' participation in physical activity: review and update. *Med Sci Sports Exerc* 2002;**34**:1996–2001.

34 Völker S, Kistemann T. Developing the urban blue: comparative health responses to blue and green urban open spaces in Germany. *Health Place* 2015;**35**:196–205.

35 Beenackers MA, Kamphuis CBM, Giskes K *et al*. Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: a systematic review. *Int J Behav Nutr Phys Act* 2012;**9**:11.